CDMA2000 RF system design software and spreadsheets

For decades, engineers have used spreadsheets for RF system design. During the initial phase of the design cycle, spreadsheets provide results for simple RF systems quickly. However, simple spreadsheet tools fail to provide insight into many critical issues when selecting the proper hardware.

By Anitha Swaminathan

Today's complex designs, particularly with the advent of digital communications standards such as code-division multiple access (CDMA2000), require a reliable performance predictive methodology that ensures a high level of confidence that a design will work right in the first iteration, before committing significant time and resources to the project. The ultimate predictor of a practical, complex system design is system design software. System design software determines the RF system performance by monitoring the trade-offs of various system specifications.

Although spreadsheet programs are economical, they often require enormous amounts of time and effort before they contribute to successful system design. Critical measurements such as dynamic circuit response, control loop characteristics and so on, cannot be determined by spreadsheets. These measurements are important for the accurate selection of hardware components.

Many real-world impairments affect system design. And simple tools like spreadsheets do not fully consider these effects. To characterize these effects, several measurements are required. Advanced Design System (ADS) from Agilent EEsof EDA is the tool that is used throughout this article for making measurements and displaying results for analysis.

Analyzing AGC loops

Automatic Gain Control (AGC) loops are important in any communications system where wide amplitude variations in the output signal lead to a loss of information. These signals need a good control to maintain a constant signal level at the output. Figure 1 shows a block diagram of an AGC loop for an amplifier with a CDMA2000 input signal.

The complexity of an AGC system is determined by the requirements of the communications system. An integrated software tool that provides top-down RF design can be used to analyze the steady-state and transient response of the control loop.

Figure 2 shows a plot of input and output power of the AGC amplifier. The amplifier and intermediate frequency (IF) output power changes in response to variations in input power due to CDMA2000 modulation, but the loop forces them back to their target levels. Here, the dynamic circuit characteris-

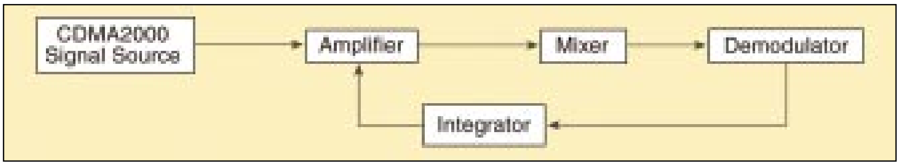

Fig. 1. A block diagram of an AGC for an amplifier with a CDMA2000 signal source.

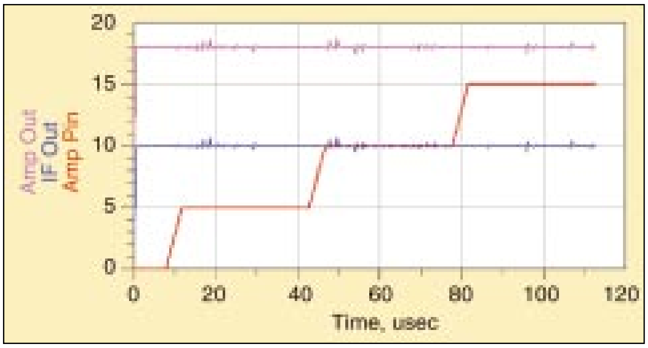

Fig. 2. Input Power, Amplifier Output Power and IF Output Power versus Time.

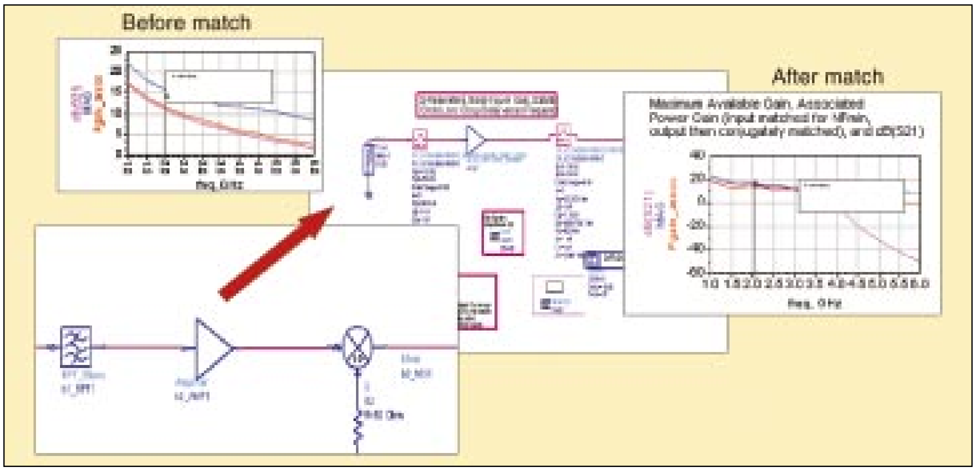

Fig.3. A high-level amplifier block pushed into the circuit level to design input and output match. The graphs show the power gain before and after matching the amplifier.

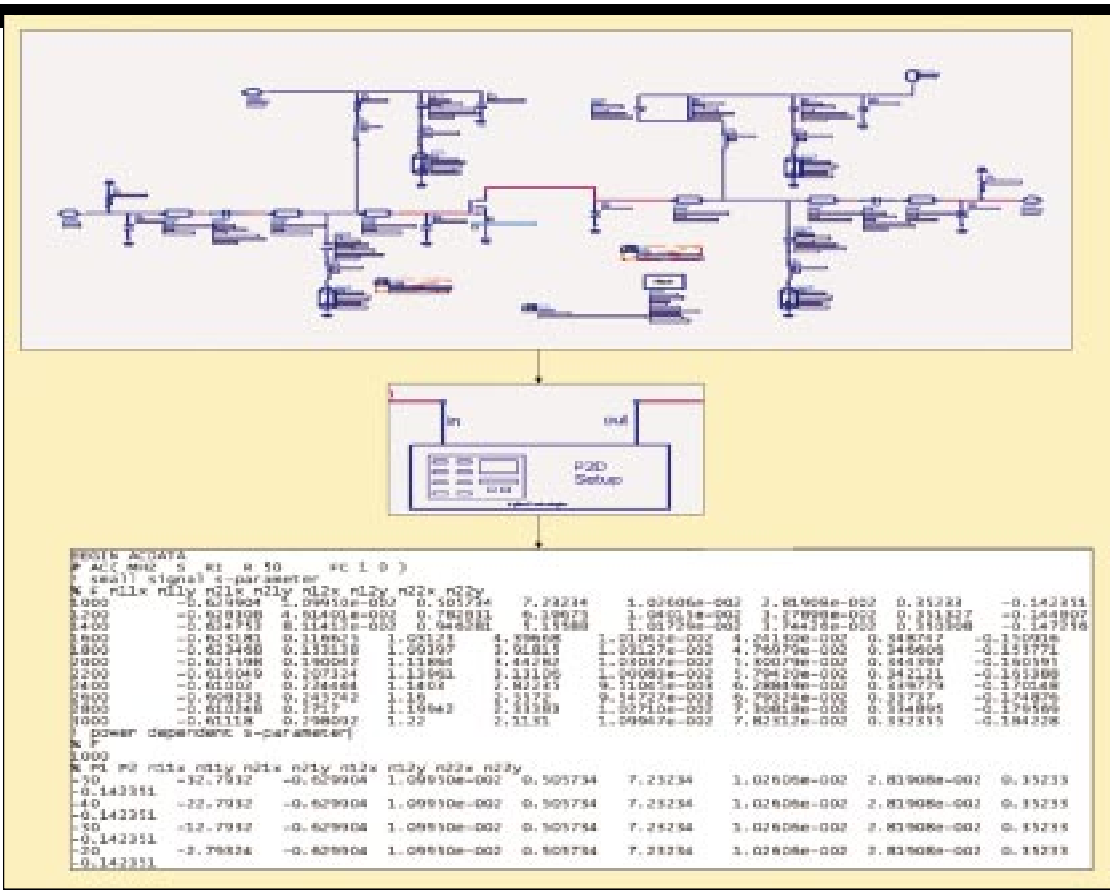

Figure 4. Single-step .P2D file extraction for an amplifier circuit using a .P2D extractor.

tics are measured, whereas spreadsheets are only capable of performing steady-state measurements and cannot address time-varying signals.

Spurious responses, TOI, and matching

Spurious responses are another example of a real-world impairment often seen in RF systems. Spurious responses usually are generated by mixers, antennas (if no pre-amplifier stage is present), nonlinear amplifiers and spectrally impure oscillators. To analyze spurious signals, the designer needs adequate selectivity ahead of the mixer stage and good linearity in the RF stage to obtain a wide, spurious-free dynamic range. Spreadsheets cannot predict spurs at all levels accurately.

Traces of spectral components, spurious frequencies, and power levels for various nodes of the design can be determined using RF system design software. The software also contains mixer models, which carry information about the intermodulation products due to mixer signal input and local oscillator mixing. Circuit-level mixers can achieve accurate prediction of spurs at all levels. The software also allows changing the intercept point and spur in mixers for analysis.

When designing RF systems, the linearity of a broadband receiver plays an important role in the overall performance. It affects system level parameters such as sensitivity and link budget. Third-order intercept point (TOI) is a good measure of linearity of the receiver. Designers can use equations on a spreadsheet to predict the worst-case, third-order intercept, but the actual TOI is beyond the scope of the tool. Actual TOI measurement is vital to improving the design performance because it can indicate a need to include selectivity between stages. System design software predicts the

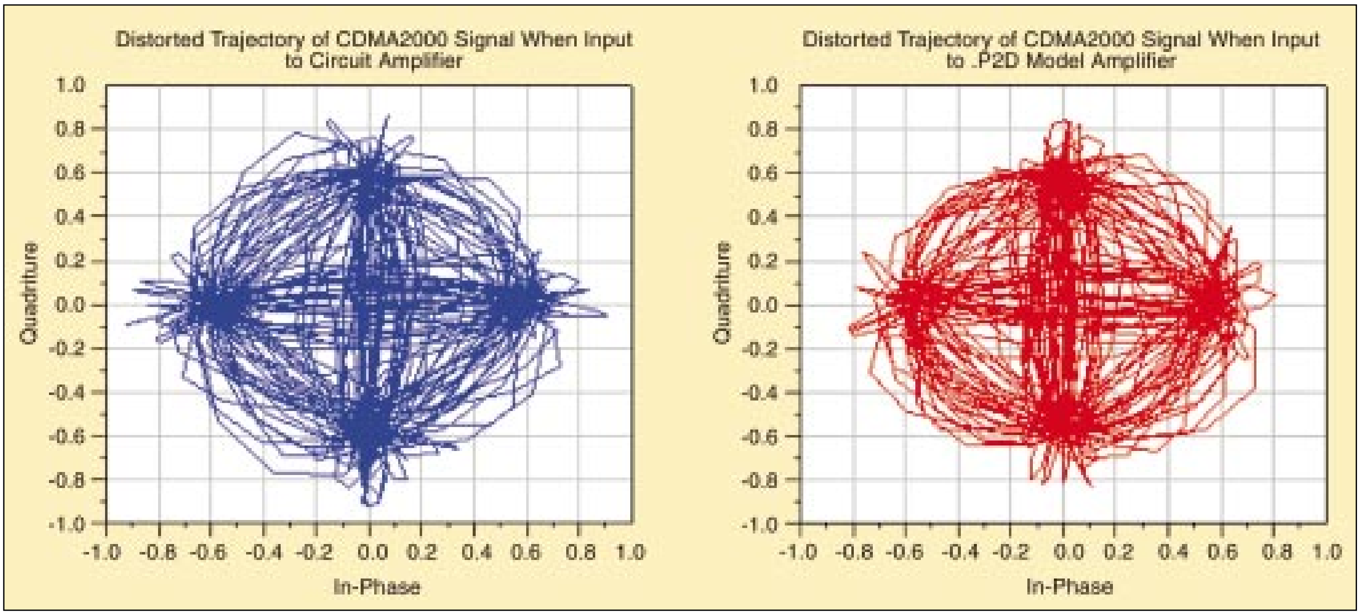

Figure 5. Distorted trajectory of CDMA2000 signal input to an amplifier .P2D model and circuit.

Measurements/Features Required for System Analysis	Spreadsheet	RF System Design Software	Comments
Signal-to-Noise Ratio	✓	✓	
Power/Voltage Frequency Spectrum	✗	✓	
Input/Output third-order Intercept Point	✗	✓	Worse-case TOI predicted using spreadsheets
Spurious Signal Analysis	✗	✓	Spreadsheets can perform spurious analysis but does not predict all levels of spurs accurately
Accuracy of Results	✗	✓	Less accurate in spreadsheets when compared to EDA software
CAD operating Cost	✓	✗	License Required
Multi-Platform	✗	✓	EDA software work on most operating systems
Steady-state Analysis	✓	✓	
Quickness of obtaining results	✓	✗	Spreadsheets can update results very quickly
Interaction between functional models. For e.g. match dependencies	✗	✓	For example, yield optimization gives interactions between component including mismatch effects on gain and noise figure (NF).
General non-linear analysis	✗	✓	Includes compression curves, phase distortion, non linear noise, etc
Detailed linear analysis	✗	✓	Includes s-parameter analysis
Statistical sweep to study worst-case performance	✗	✓	
Analysis with complex modulated sources	✗	✓	For example, CDMA2000, 3-GPP, wireless local area network (WLAN) standard signals
Predicting control loop effects	✗	✓	For e.g. AGC loop time in amplifier
In-band and out-of-band intermodulation for multiple harmonics	✗	✓	For example, a spur can travel from a phase locked loop (PLL) to other functional modules even if filters filter most of it
Dynamic circuit response using Based Analysis	✗	✓	Spice, convolution, circuit envelope Time-
Analyze physical design	✗	✓	Electromagnetic (EM) analysis, layout steady-state behavioral and dynamic circuit
Use of instrumentation to form connected solutions design verification	✗	✓	Connecting the software to a network analyser and pulling the component details.

Table 1. RF system design measurements - Spreadsheets vs. RF system design software.

actual TOI for multi-tone frequencies with harmonics in seconds if the software contains a harmonic balance simulator.

During the initial design phase of a high-level system, certain assumptions are made for each block in the system. One such assumption, very common in spreadsheet analysis, is that the amplifier is matched to 50 Ohms. But in reality, the amplifier usually has mismatches in the input and the output of the actual hardware implementation. Any such mismatch will degrade the overall system gain. RF design experts can perform narrowband matching using spreadsheets. However, RF system design software usually contains a narrowband and broadband matching synthesis utility that designers can use to design matching elements that work well in the first run. This type of linear analysis is available in almost all RF design software and quickly identifies a poor match.

Perfect matching of amplifier designs is important for aerospace defense/satellite communications applications. Consider a high-level system such as the one in Figure 3, which shows a series of blocks that contain circuit representations inside them in the hierarchy. The complex terminations in every block can be identified with linear analysis. If the amplifier is poorly matched, the designer can open up (push into) the circuit level of the amplifier block and perform narrowband/broadband matching using the matching utility, as shown in Figure 3. After the matches are designed, the circuit can be pushed back to block level and simulated. The gain of the overall system is improved. Using hierarchical designs reduces the complexity of the design and saves simulation time. Each block can be accurately designed by pushing into the circuit level of each block and optimizing its performance.

Now consider a system built on a substrate. Spreadsheets fail to design such systems accurately because narrowband effects cannot be predicted unless the designer knows the component data such as voltage standing

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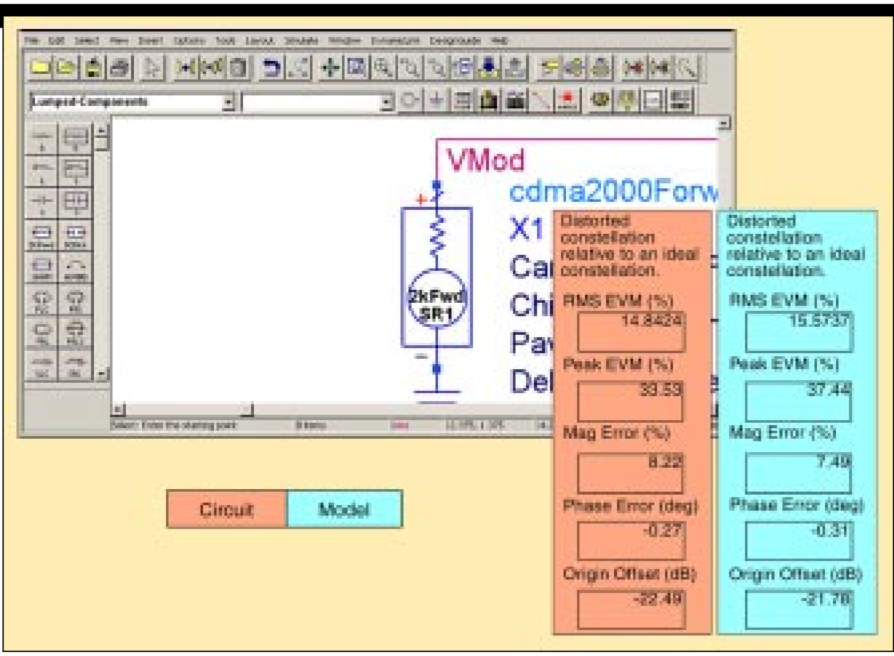

Figure 6. A snapshot of a high-level CDMA2000 signal source in the background and EVM results using a circuit and P2D model of an amplifier in the foreground.

wave ratio (VSWR). One way to do this is to read the component datasheet and manually type the data into the spreadsheet to perform narrowband analysis. Sophisticated RF system design software can be connected to a vector automated network analyzer to automatically read the component data to the software via a hardware-software connection. This method requires minimum time and effort and allows much data to be imported for various components, resulting in more accurate performance predictions.

Behavioral models

Behavioral models are commonly used in high-level system design in most system design software. The advantage is that behavioral models reduce system simulation time. The disadvantage is often a compromise in results accuracy. On the other hand, behavioral models that are extracted from circuit level components reduce simulation time and provide more accurate results. Figure 4 shows the extraction of the .p2d model of the amplifier. These models are extracted in a single-step process using the model extractor. Another benefit of model extraction is intellectual property (IP) protection because dataset can be passed around without the circuit details. These models contain RF circuit impairment effects, S-parameters, power, and narrowband effects.

Due to the complex modulation of CDMA2000 signal source, performance of the system cannot be determined without considering the the modulation. With electronic design automation (EDA) software that has a design and verification environment for a communications standard, a designer can generate a viable design easily that will work correctly in the first iteration. Wireless standard-specific component libraries and menu-accessed pre-built templates and test

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benches are available to verify if the system is compliant with a particular wireless standard. The complex modulated sources can be used in the system/circuit simulations with a circuit envelope simulator. This is the only simulation technology that allows simulation of circuits with time-varying complex modulation. Complex modulated sources also can be used for circuit simulation without co-simulation using circuit envelope simulator.

The CDMA2000 signal is input to the circuit amplifier in the first setup and then to the extracted .P2D model of the amplifier in the second setup. The distorted trajectory of the signal is compared in these two setups. They have excellent matching, as shown in Figure 5.

The CDMA2000 complex modulated source is input to an amplifier circuit, and the error vector magnitude (EVM) is measured. The same result is again measured by replacing the amplifier circuit with an extracted .P2D model. The results shown in Figure 6 are close when compared to the actual circuit results. Designers have the advantage of selecting the components and system specifications under actual operating conditions during the initial phase of the design. This will save significant design and simulation time for large complex systems.

Statistical sweep

Another major advantage of using RF system design software is statistical sweep analysis. Performing statistical sweep of variables is complex in spreadsheets. In most cases, the analysis is done at a single point in each run. Design software can analyze results for a range of values in the first run to study the worst-case performance. For example, measurements like yield optimization that contains interactions between each component including mismatch effects on gain and noise figure (NF) can be easily done using system design software.

Comparison summary

Table 1 gives a comparison of spreadsheets and RF system design software for various measurements that are key to successful RF system design.

This article demonstrates many of the real-world impairments that can affect system design. Simple tools like spreadsheets do not consider these impairments and provide inaccurate results during the initial phase of the design. Ever-increasing system complexity continues to absorb more effort and design time. By carefully implementing these effects via design simulation software, accurate results can be achieved in the initial phase of the design to minimize manufacturing risk. RFD

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